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October 12, 2018

Via Electronic Filing

Marlene H. Dortch
Secretary
Federal Communications Commission
445 Twelfth Street SW
Washington, DC 20554

Re: *Request by Google LLC for Waiver of Section 15.255(c)(3) of the Commission's Rules (ET Dkt. No. 18-70)*

Dear Ms. Dortch:

Google LLC (Google) supplements the record with data demonstrating that a waiver to allow for operation of Project Soli sensors at power levels higher than those in Section 15.255(c)(3) of the Commission's rules is necessary to allow users in the United States to have an experience sufficiently comparable to that enjoyed by users in other countries when operating this promising new technology. Specifically, as requested by Commission staff, Google submits an analysis showing how Soli's gesture recognition is impacted by its transmission power level. In addition, consistent with previous analyses,¹ Google is here submitting a study further demonstrating the lack of harmful interference created when a Soli sensor is placed near a WiGig access point (AP).

Higher Power Levels Lead to Better User Experiences with Soli Sensors

Operational power levels have a meaningful impact on the effectiveness of Soli sensors, which is vital to consumers' willingness to adopt the technology.

¹ See Google LLC Request for Waiver in ET Docket No. 18-70 (filed Mar. 7, 2018) (Petition) (attaching Dr. Stefan Mangold, Lovefield Wireless GmbH, *Assessing the Interference of Miniature Radar on Millimeter Wave 60 GHz Wi-Fi* (Feb. 21, 2018)); Letter from Megan Anne Stull, Counsel, Google LLC, to Marlene H. Dortch, Secretary, FCC, in ET Docket No. 18-70 (filed June 8, 2018) (attaching Dr. Stefan Mangold, Lovefield Wireless GmbH, *Assessing the Interference of Miniature Radar on Millimeter Wave 60 GHz Wi-Fi — Supplemental Analysis* (June 8, 2018) and Qi Jiang et al., *Measurement Study on Soli/802.11ad Coexistence* (June 2018) (Jiang et al.)).

Google simulations² (appended as Attachment A) analyzed how effectively Soli sensors recognized horizontal swipes of the hand from distances between 10 cm and 100 cm at three different Equivalent Isotropically Radiated Power (EIRP) levels: the level for short-range devices for interactive motion sensing in the U.S. under Section 15.255(c)(3);³ the 13 dBm level discussed in Google's and Facebook's joint letter in this proceeding;⁴ and the 20 dBm level allowed by the international ETSI standard EN 305 550.⁵ The simulations show that the Soli sensor's ability to track ordinary hand and finger motions that humans can execute naturally increases at higher EIRP.

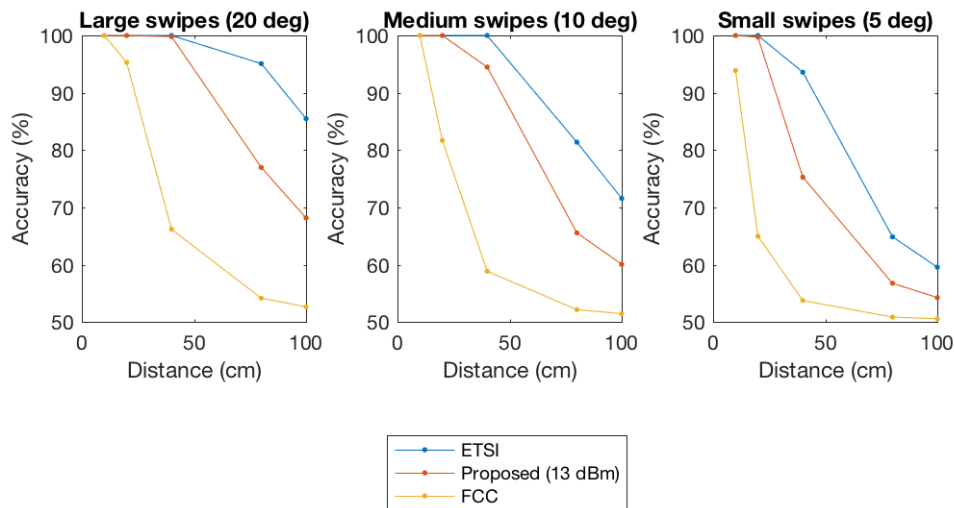
As shown in the graphs below, with presently available Soli technology, the peak transmitter conducted output power currently authorized under Section 15.255(c)(3) would not ensure high-quality interaction and satisfactory user experience. At 13 dBm EIRP, commercially acceptable Soli use cases would become possible, but would be limited to those involving short range interaction. While this higher power level would allow for successful deployment using presently available technologies, it may limit development of future applications. At 20 dBm EIRP, simulations indicate that gestures from small "flicks" to broad "swipes" could be detected at close distances by a Soli sensor. Thus, power levels (conducted and EIRP) greater than those in Section 15.255(c)(3) of the Commission's rules are essential for successful adoption and operation of Soli technology.

² See Jian Wang & Jaime Lien, *Gesture Classification Performance Estimate Under Regulatory Limits* at 8-10 (Oct. 2018) (Attachment A).

³ See 47 C.F.R. § 15.255(c)(3). The study in Attachment A used -10 dBm conducted power and 6 dBi antenna gain, which is equivalent to -4 dBm EIRP. Although the FCC allows up to +10 dBm EIRP, achieving such a level while abiding by the -10 dBm conducted limit is only possible with a highly directional 20 dBi antenna. An antenna with such high directionality, however, is not consistent with a gesture recognition device that must sense across a wide area. For this reason, a realistic 6 dBi antenna gain is used in the study. See Attachment A at 8-10.

⁴ Letter from Megan Anne Stull, Counsel, Google LLC, and Pankaj Venugopal, Associate General Counsel, Facebook, Inc., to Marlene H. Dortch, Secretary, FCC, in ET Docket No. 18-70 at 2 (filed Sep. 7, 2018).

⁵ See ETSI, *Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Short Range Devices (SRD); Radio Equipment to be Used in the 40 GHz to 246 GHz Frequency Range; Part 2: Harmonized EN Covering the Essential Requirements of Article 3.2 of the R&TTE Directive*, ETSI EN 305 550-2 V1.2.1 (Oct. 2014), at https://www.etsi.org/deliver/etsi_en/305500_305599/30555002/01.02.01_60/en_30555002v010201p.pdf (EN 305 550).



Soli Technology Will Not Generate Harmful Interference to 802.11ad APs

In June 2018, Google filed with the Commission a report measuring the real-world impact of Project Soli technology on a commercially available WiGig laptop client, with emphasis placed on proximity to a Soli sensor.⁶ For completeness and using a similar methodology, Google has since taken additional measurements with a Soli device positioned near an off-the-shelf AP. The results, appended as Attachment B,⁷ show that, in general, positioning the Soli device next to the AP in the new configuration resulted in even less effect on WiGig than when the Soli device was positioned near a client. Consistent with Google's previous studies, data from this supplemental analysis supports the conclusion that Soli technology is unlikely to create harmful interference to 802.11ad APs in real-world scenarios.

The record addresses all reasonable concerns that have been expressed about harmful interference and supports expeditious grant of the requested waiver. Granting the waiver would promote the public interest and "encourage the provision of new technologies and services to the public" consistent with Section 7 of the Communications Act of 1934.⁸ Google respectfully requests that the Commission swiftly act to enable certification, marketing, and effective operation of the Project Soli devices subject to the requested waiver.

Please do not hesitate to contact me with any questions.

Sincerely,

Megan Anne Stull
Counsel, Google LLC

⁶ See generally Jiang et al.

⁷ See Gary Wong et al., Google LLC, *Supplement to Measurement Study on Soli/802.11ad Coexistence* (Oct.12, 2018) (Attachment B).

⁸ See 47 U.S.C. § 157(a).

ATTACHMENT A

Gesture classification performance estimate under regulatory limits

Jian Wang, Jaime Lien

October 2018

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Introduction

This document describes an analysis of Soli gesture recognition accuracy under three different transmission power limits:

Regulation	Peak EIRP (dB)
FCC: Field-disturbance sensor used as Short Range Device (SRD) for interactive motion sensing under FCC rule 15.255(c)(3)	-10 dBm conducted power +6 dB antenna gain = -4 dBm EIRP
Proposed: Power level allowing for acceptable operation in U.S. and Europe	+13 dBm EIRP
ETSI non-specific SRD EN 305 550	+20 dBm EIRP

The analysis considers the swipe gesture, which entails a horizontal motion of the hand in front of the Soli sensor. The swipe gesture is classified according to the direction of motion (left to right or right to left). Successful gesture recognition requires motion detection and direction classification based on angular position estimates of the hand.

Target model

The hand is modeled as a target with radar cross section of -40 dBsm, based on measurements in the literature.¹ Gestures performed at distances of 10 cm, 20 cm, 40 cm, 80 cm, and 100 cm from the sensor are considered.

The angular extent of the gestures is varied to account for the potential for various use cases for the sensors.

Signal-to-Noise Ratio (SNR)

The SNR impacts the variance of the angular estimate, as described later in the document. SNR is a function of transmitted power P_t , antenna gain, noise figure, target RCS, distance R , and other system gains and losses. The contributions of these factors to SNR are calculated for the IFX radar chip based on the measured antenna gain and hardware specifications, combined with modeled free-space path loss ($1/R^4$ fall-off due to loss in each direction). The resulting SNR of a hand as a function of angular position and distance is shown in Figure 1 for the three transmission power limits.

¹ See generally Philipp Hügler et al., *RCS Measurements of a Human Hand for Radar-Based Gesture Recognition at E-band* (Mar. 2016), available at <https://ieeexplore.ieee.org/document/7461605>.

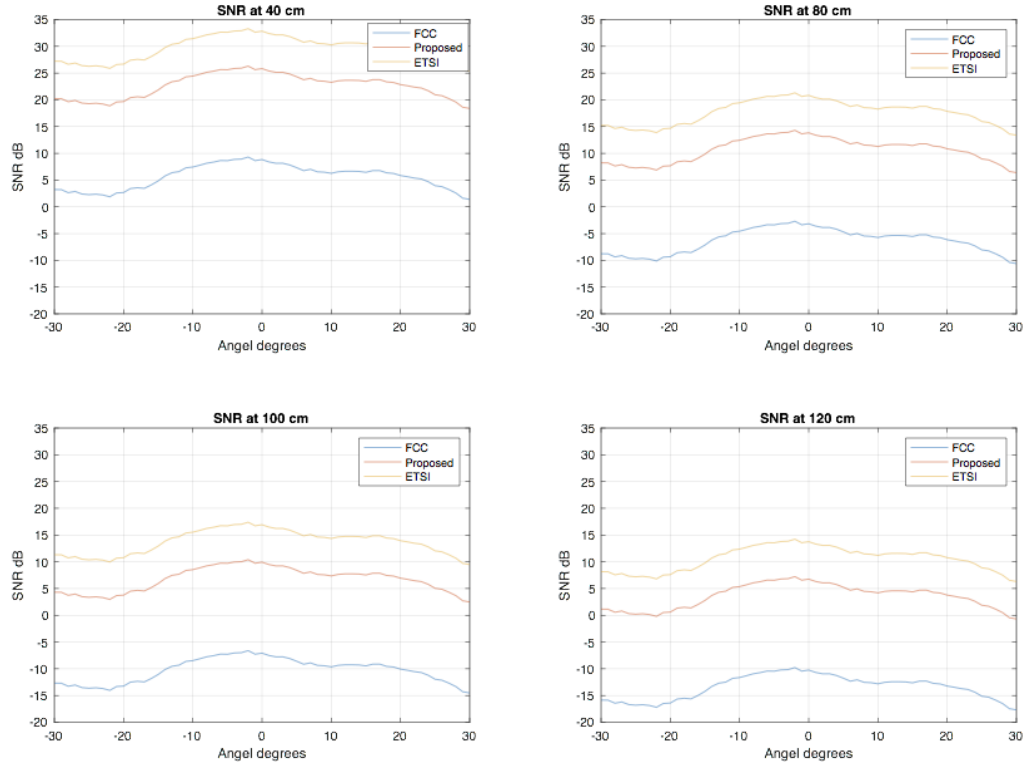


Figure 1. Average SNR of a typical hand at various distances

Angular estimation

The target angular position is computed from the interferometric phase, i.e. the difference in received phase between two receive antennas. The geometry of the target relative to the receive antennas is shown in Figure 2.

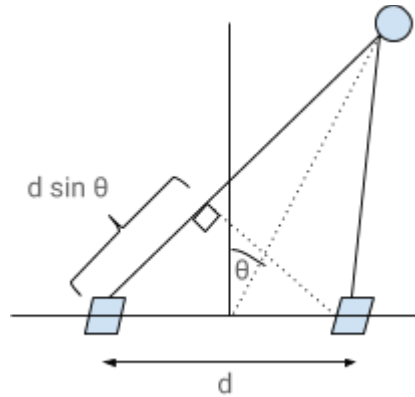


Figure 2: Angular estimation geometry

The phase measurement $\hat{\phi}$ is modeled as the sum of several terms:

$$\hat{\phi} = \phi_{true} + \phi_{bias} + \phi_{noise}$$

where ϕ_{true} is the ideal interferometric phase, ϕ_{bias} is a systematic hardware-dependent bias, and ϕ_{noise} is random noise. These terms are described in detail below.

Ideal interferometric phase

The ideal interferometric phase ϕ_{true} is a function of the reflection's direction of arrival θ :

$$\phi_{true} = \frac{2\pi d}{\lambda} \sin(\theta)$$

where d is the distance between antenna elements and λ is the wavelength. This function is plotted in Figure 3.

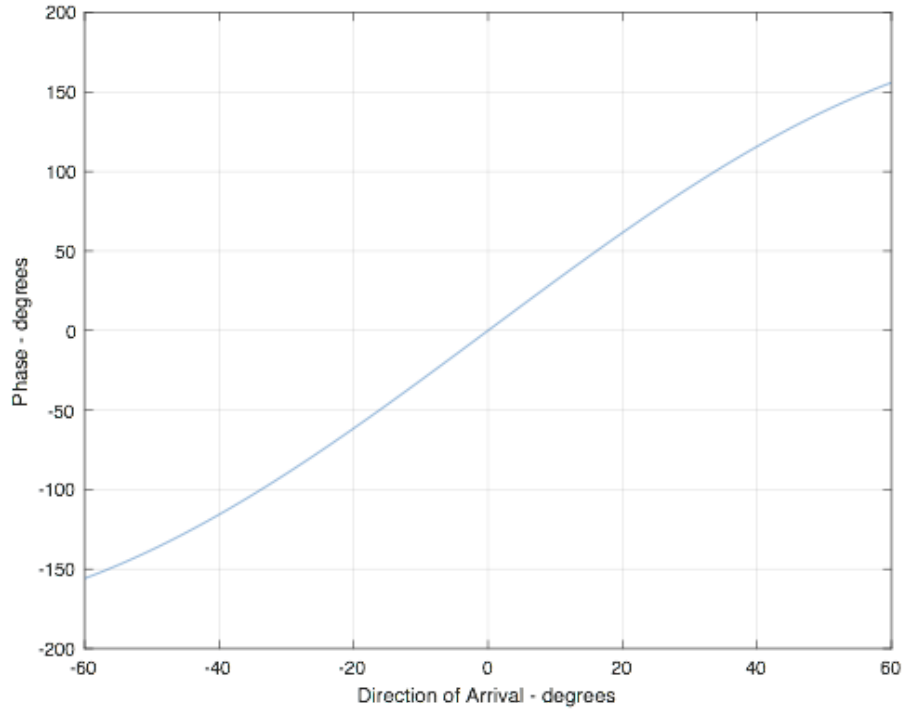


Figure 3. Ideal interferometric phase ϕ_{true} as a function of direction of arrival θ

Interferometric phase bias

The bias term ϕ_{bias} is a function of physical effects of the radome and imperfections in the physical antenna. The phase bias for the Soli device was determined by direct measurement in an anechoic testbed. Figure 4 shows the measurement result.

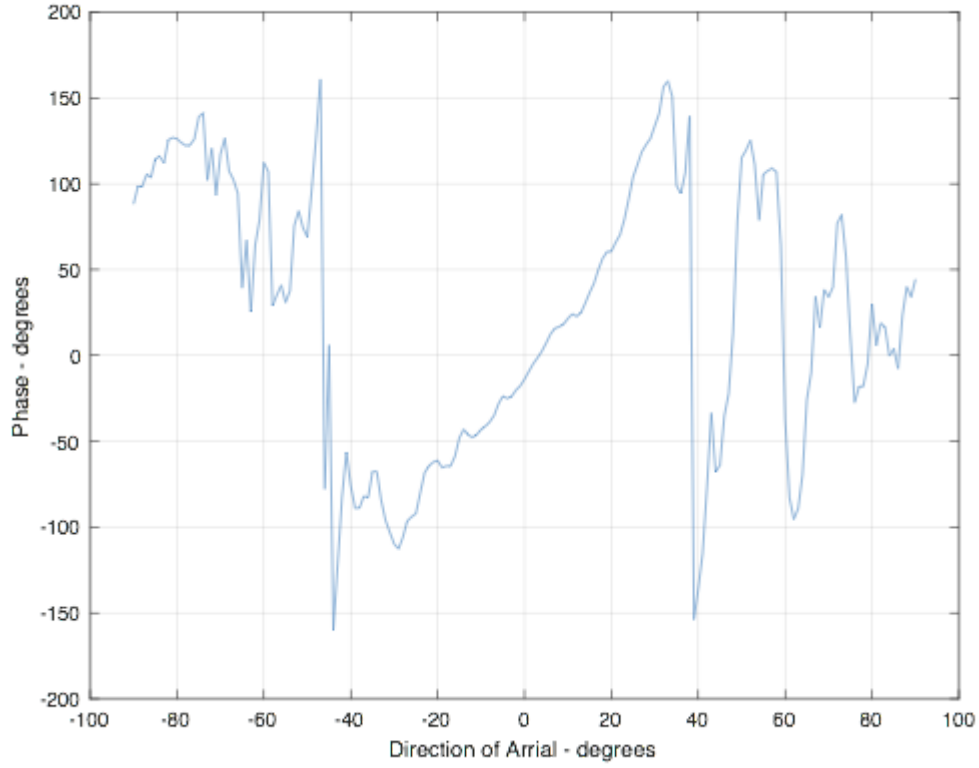


Figure 4. Measured results of $\phi_{true} + \phi_{bias}$ as a function of true angle θ

Interferometric phase noise

The noise term ϕ_{noise} is commonly modeled as Gaussian with zero mean and variance σ^2 :

$$\phi_{noise} \sim N(0, \sigma^2).$$

The variance σ^2 of the noise distribution is a function of SNR and antenna aperture, which depends on the angle θ relative to boresight:

$$\sigma = \frac{2}{\pi\sqrt{SNR}\cos(\theta)}$$

The SNR of the Soli sensor as a function of transmission power and distance is described above.

Phase measurement distribution

Accounting for all three phase terms, the total measured phase is a random variable with the following Gaussian distribution:

$$\hat{\phi} \sim N(\phi_{true}(\theta) + \phi_{bias}(\theta), \sigma^2(P_t, R, \theta)).$$

The notation above indicates the dependencies of the bias terms ϕ_{true} and ϕ_{bias} on target angle θ , as well as the dependency of variance σ^2 on transmit power P_t , distance R , and target angle θ .

Gesture classification performance

The following simulation was performed to determine swipe classification performance.

Gesture model

A swipe moving from left to right was considered.

The swipe was assumed to occur within $\pm \theta_{max}$ degrees of boresight, covering an angular extent of $2\theta_{max}$ degrees, and passing through boresight. The simulation parameter θ_{max} was varied to analyze the effect of different swipe sizes. The hand's distance from the sensor (R) was simulated at 20 cm, 40 cm, 80 cm, and 100 cm.

Simulation parameter	Symbol	Values
Angular extent	$2\theta_{max}$	5° (small swipe) 10° (medium swipe) 20° (large swipe)
Range	R	10 cm 20 cm 40 cm 80 cm 100 cm

The left-most point is labeled as P_{left} with radial coordinates $(R, -\theta_{max})$ and the right-most point as P_{right} with radial coordinates $(R, +\theta_{max})$, as shown in Figure 5. These two points represent two points within the trajectory of the swipe where the hand is detected and the angular position is measured from the interferometric phase.

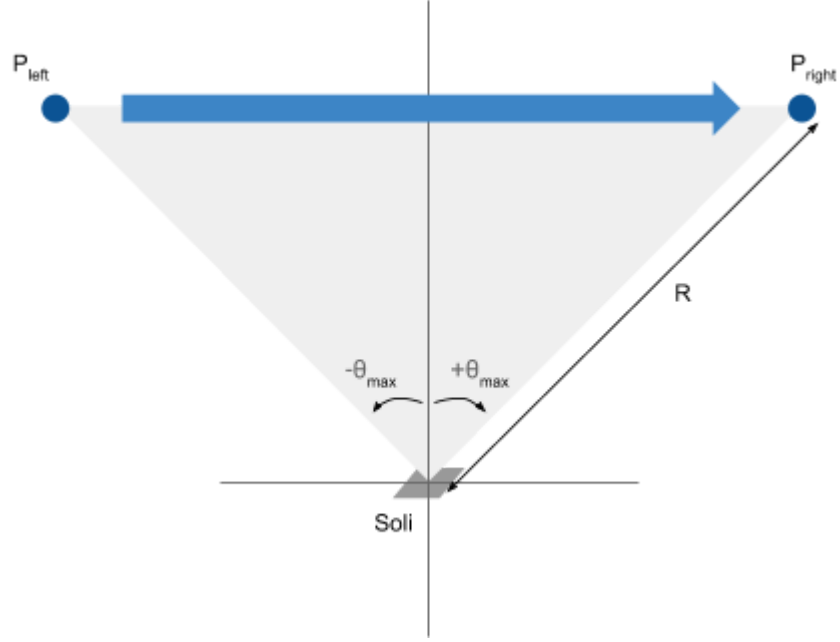


Figure 5: Geometry of simulated gesture.

Simulation

For each of the two points, the angular measurement was simulated by randomly drawing from the interferometric phase distribution modeled in the previous section. The simulated interferometric phase measurements at P_{left} and P_{right} are thus respectively given by

$$\hat{\phi}_{left} \sim N\left(\phi_{true}(-\theta_{max}) + \phi_{bias}(-\theta_{max}), \sigma^2(P_t, R, -\theta_{max})\right),$$

$$\hat{\phi}_{right} \sim N\left(\phi_{true}(+\theta_{max}) + \phi_{bias}(+\theta_{max}), \sigma^2(P_t, R, +\theta_{max})\right).$$

The resulting simulated gesture classification was determined based on the relation between the instantiated values of $\hat{\phi}_{left}$ and $\hat{\phi}_{right}$, as described in the table below.

Condition	Simulated gesture classification
$\hat{\phi}_{left} < \hat{\phi}_{right}$	Left to right (correct)
$\hat{\phi}_{left} > \hat{\phi}_{right}$	Right to left (incorrect)

For each combination of gesture angular extent and range parameter values, 10^7 simulations were performed. The overall accuracy was calculated as the percentage of correct classifications.

Results

The results of the simulation are summarized in the table and plots below.

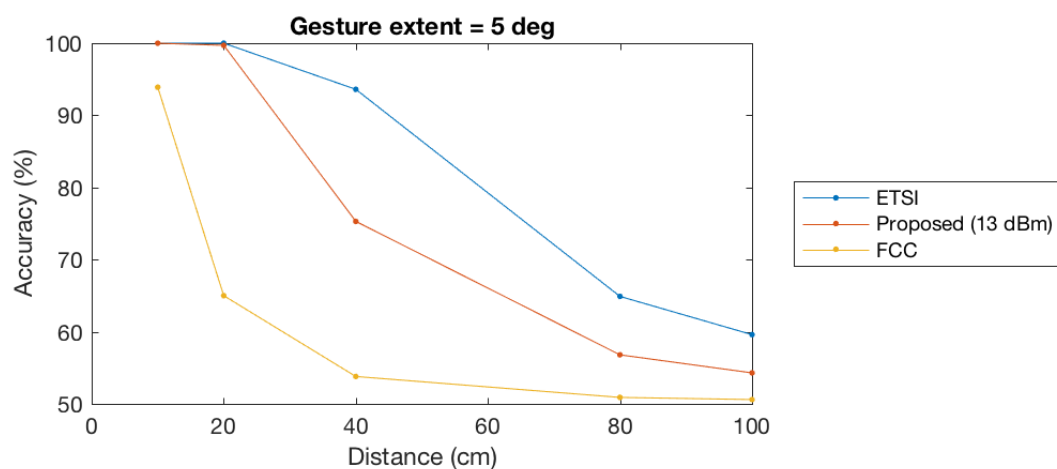
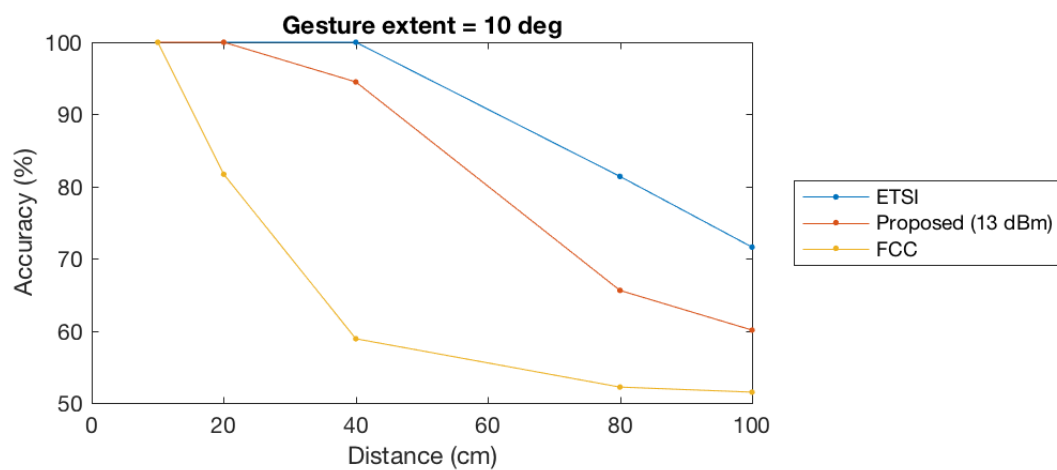
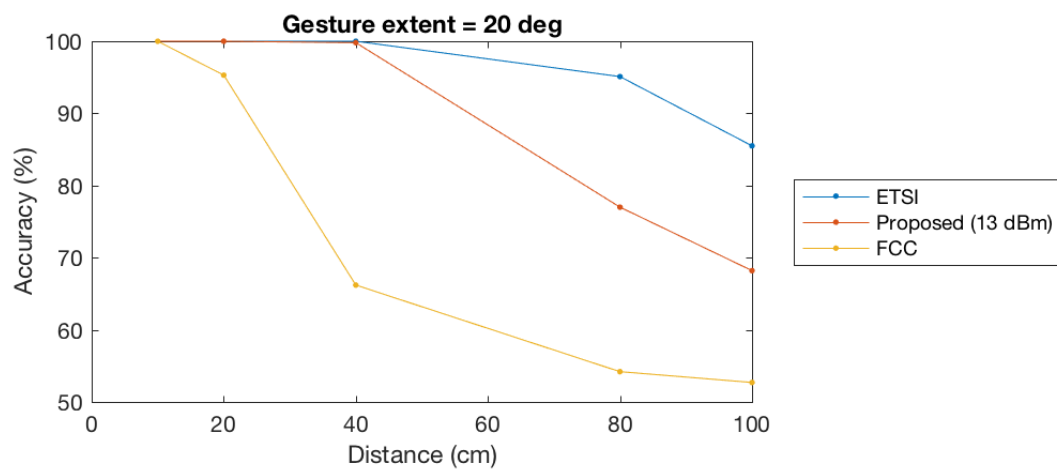
Acceptable use case conditions are indicated in **red** for the 13 dBm power level that would allow for equivalent customer experience between Soli devices in the U.S. and in Europe using current technology and in **green** for ETSI standard EN 305 550. In **yellow** are use case conditions that are acceptable under the current FCC rule. The results demonstrate that with the increase of power (i.e. to the levels permitted in EN 305 550) the number of use cases for successful use of Soli sensors increases. Indeed, with 20 dBm EIRP, a variety of gestures from small “flicks” to broad “swipes” could be detected at close distances by the Soli sensor.

At 13 dBm EIRP, Soli use cases might well be limited to short range interaction. This would allow for successful deployment in a number of products, but could be limiting for development of future applications. Put simply, at lower power levels, it is more difficult for the Soli sensor to track fast and fluid hand and finger motions that humans can execute effortlessly when interacting with small objects.

The power level in FCC rule 15.255(c)(3) would not ensure high quality of interaction and user experience when using swipe motions.

Distance	Gesture	Accuracy		
		FCC current rule -10 dBm conducted power + 6 dBi antenna gain = -4 dBm EIRP	Proposed compromise 13 dBm EIRP	ETSI 20 dBm assuming average PSD does not limit
10 cm	Large	100.00%	100.00%	100.00%
	Median	99.98%	100.00%	100.00%
	Small	93.86%	100.00%	100.00%
20 cm	Large	95.30%	100.00%	100.00%
	Medium	81.67%	100.00%	100.00%
	Small	65.00%	99.70%	100.00%
40 cm	Large	66.20%	99.80%	100.00%
	Medium	58.90%	94.50%	99.98%
	Small	53.80%	75.30%	93.60%
80 cm	Large	54.20%	77.00%	95.10%

	Medium	52.20%	65.60%	81.40%
	Small	50.90%	56.80%	64.90%
100 cm	Large	52.70%	68.20%	85.50%
	Medium	51.50%	60.10%	71.60%
	Small	50.60%	54.30%	59.60%



ATTACHMENT B

Supplement to Measurement Study on Soli/802.11ad Coexistence

Gary Wong, Qi Jiang, Raj Nijjar, Dave Weber
Google LLC
October 12, 2018

Summary

Additional measurements taken with the Soli device positioned near an Access Point (AP) show that interference with WiGig is similar to or less than the levels of interference previously reported with the Soli device near the client.

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Introduction

In June, Google filed a report with the FCC¹ measuring the real-world impact of Project Soli technology on a commercially available WiGig link (primarily focusing on proximity to the client). For the sake of completeness and using similar methodology, we supplement that study to document the effect of Project Soli near an AP.

¹ Letter from Megan Anne Stull, Counsel, Google LLC, to Marlene H. Dortch, Secretary, FCC, in ET Docket No. 18-70 (filed June 8, 2018) (attaching Qi Jiang et al., *Measurement Study on Soli/802.11ad Coexistence* (June 2018)) (June Study).

Impact of Soli technology near an 802.11ad AP

Test Setup

The test setup was largely the same as reported in the June Study. In this case, the Soli device has been positioned near an AP.

The test was conducted in an indoor office environment without people present in the vicinity of the test setup. Test equipment was comprised of:

1. 1x Netgear Nighthawk X10 R9000 802.11ad AP
2. 1x Acer laptop (N16C5) with built-in 802.11ad capability
3. 1x Infineon Soli reference board (BGT60TR24C application board)

A desktop server was connected via 1Gbps Ethernet to the Netgear AP, which ran the iPerf server. A laptop (not pictured below) was used to control the Soli board.

A diagram of the test setup is below:



For the purposes of this study, “uplink test” refers to a transfer of data from the 802.11ad client laptop to the 802.11ad AP, and “downlink test” refers to a transfer of data from the 802.11ad AP to the 802.11ad client laptop.

An Infineon reference design was used as the Soli device. This device was operated in the following condition, which corresponds to the currently expected duty cycle for the Soli gesture sensing technology when it is active during a triggering event:

- TX conducted power: +7dBm
- TX max antenna gain: +6 dBi
- Frequency of chirp: 57.5 - 63.5 GHz
- Duration of chirp: 37 us
- Chirp repetition rate: 1400 Hz

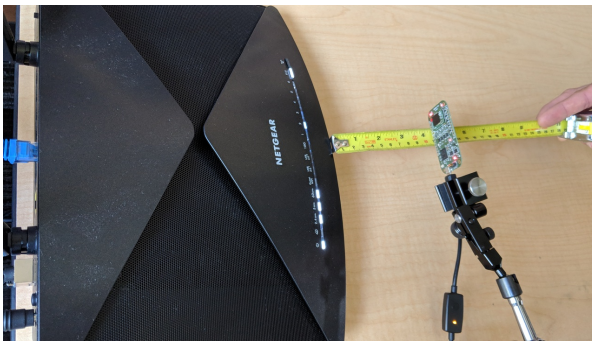
Soli Placement Relative to 802.11ad Antenna

The antenna in the Netgear X10 AP, which was located through use of a spectrum analyzer and a horn antenna, is positioned in the front panel of the device (shown in red in below diagram).



While Soli was active, we identified the worst case position for the Soli device (i.e., where WiGig throughput was maximally degraded). Because we found that positions in which the Soli device was not directly pointed at the AP antenna in a co-linear path to the client had a negligible effect on WiGig performance, we did not record this data. Instead, we focused exclusively on the worst case configuration, even though it likely will occur in a minority of real world situations.

Configuration 1: Soli technology four inches away from the 802.11ad antenna. This position was chosen through experimentation as the point where the maximum throughput degradation occurred when Soli was active. The client device was approximately 3 feet away, positioned with a line-of sight path to the AP.

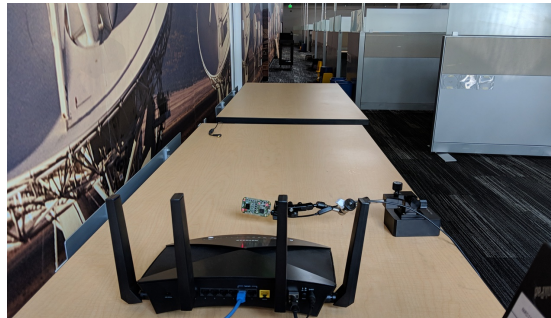


1-a



1-b

Configuration 2: Same as configuration 1, except client device is moved approximately 50 feet away.



2-a

Test Procedure

At the locations above, the 802.11ad AP performance was measured both with the Soli technology transmitting and with the Soli technology turned off as follows:

- Measure both uplink and downlink throughput for a clean 802.11ad link without the Soli technology.
- Move the Soli technology to the position described above.
- Measure both uplink and downlink throughput in sequence with the Soli technology turned off.
- Measure both uplink and downlink throughput in sequence with the Soli technology turned on.

The 802.11ad AP link operated on channel 2, which spans 59.40 - 61.56 GHz and falls inside the Soli chirp frequencies of 57.5 - 63.5 GHz. Both uplink and downlink iPerf traffic were measured.

Results

The test results are presented in the table below; throughput is displayed in Mbps.

Traffic	Soli Status	Worst Case Positions	
		1 (client 3 ft away)	2 (client 50 ft away)
Uplink	ON	857	706
	OFF	889	813
Downlink	ON	553	597
	OFF	708	713

In this worst case set of positions in which Soli is pointing directly into the victim AP and aligned with the intended WiGig client, the WiGig throughput is impacted by less than 22%.

As noted, no throughput degradation was observed in cases where the Soli device was not directly between the AP and client. Because interference was negligible in these cases, the data was not recorded.

Conclusions

In general, positioning the Soli device next to the AP in a worst-case configuration resulted in limited throughput degradation of the WiGig link, and even less effect than positioning the Soli device near the client. Google's June Study found several positions where the Soli device was near the client but not directly in the path of the AP where WiGig throughput degradation could be observed. This study, however, found that, with the Soli device near the AP, the Soli device needed to be positioned directly in the path of the client to cause measurable interference. Furthermore, the worst case throughput degradation was lower when the Soli device was facing the AP compared to the findings of the previous report where the Soli device was facing the client. This may be due to a better antenna design in the AP, and other compromises made by the industrial design of the laptop client.

With previous studies, this data supports the conclusion that Soli technology is unlikely to harmfully interfere with 802.11ad technology in real-world scenarios.